Disk-Jet Connection in Active Supermassive Black Holes

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Challenges of AGN Jets @ Mitaka, 2017-01-19
• Supermassive black holes co-evolve with galaxies (e.g. Kormendy & Gebhardt 2001; Merritt & Ferrarese 2001)

• Their radiation and/or jets affect the surrounding gas from galactic to cluster scales (e.g. Fabian ’12).

• *How disks, jets, and BHs are connected?*
A fundamental plane among radio jet, X-ray disk luminosities, and black hole mass (e.g. Merloni+’03).

AGN disk luminosity is dominated in optical not in X-ray.

Core radio luminosity is used. Extended emission is important for the jet activity.

Only ~150 samples.
Big Data Science Era

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SDSS-NVSS Quasars

- SDSS-DR7 (Shen+’11)
- NVSS @ 1.4 GHz (Condon +’98)
- Total number of sources:
  - 8461
- Our quasar samples have $\lambda_{\text{Edd}} > \sim 0.01$

Redshift Distribution

$YI +’16$
Estimating Jet Power

- an empirical relation between radio luminosity and jet power (Willott+’99)

\[ P_{\text{jet}} = 9.5 \times 10^{46} \left( \frac{f}{10} \right)^{3/2} \left( \frac{L_{151} \text{ MHz}}{10^{28} \text{ W Hz}^{-1} \text{ sr}^{-1}} \right)^{6/7} \text{[erg s}^{-1}] \]

- calibrated by X-ray cavity & hot spot measurements (Godfrey & Shabala ’13).
Disk Luminosity & Jet Power

- Jet power moderately correlates with disk luminosity.

\[
\log P_{\text{jet}} = \log L_{\text{disk}} + (-0.81 \pm 6.2 \times 10^{-3})
\]

- Jet production efficiency

\[
\eta_{\text{jet}} \equiv \frac{P_{\text{jet}}}{\dot{M}_{\text{in}} c^2} = \frac{P_{\text{jet}}}{L_{\text{disk}} / \varepsilon}
\]

- Disk radiative efficiency

\[
\varepsilon = 0.1
\]

- From the correlation,

\[
\langle \eta_{\text{jet}} \rangle \approx 7.1^{+25.3}_{-5.5} \times 10^{-3}
\]
Comparison with Blazars

• Blazar spectral studies suggest
  • $\eta_{\text{jet}} = 1 \sim 10$ (Ghisellini+’14 for FSRQs, YI & Tanaka ’16 for HBLs)

• But, assuming minimum electron Lorentz factor $\gamma_{\text{min}} \sim 1$.

• If $\gamma_{\text{min}} = m_p/m_e$, $\eta_{\text{jet}}$ will be $\sim 0.01$ (YI & Tanaka ’16).
Spin Distribution

- Blandford-Znajek (BZ) process extracts jet power from the rotation of BHs through threaded magnetic fields (Blandford & Znajek ‘77; Tanabe & Nagataki ’08, Tchekhovskoy+’10, ‘11).

$$\eta_{\text{jet,BZ}} \equiv P_{\text{BZ}}/\dot{M}_\text{in}c^2 \approx 10(\phi_{\text{BH}}/50)^2 x_a^2 f(x_a)$$

- Spin parameters: $<a> \sim 0.1$ assuming $\Phi_{\text{BH}} = 50$. 

spin distribution with $\Phi_{\text{BH}} = 50$
Distribution of SMBH spins

- X-ray spectroscopy (Fe Kα line diagnostics) suggests spin parameters of $a\sim 1$ for SMBHs (e.g. Reynolds '14)

- But, these results strongly depend on how we define the continuum (see e.g. Noda+'11)

![Graph showing distribution of SMBH spins vs. SMBH mass](image)
Measuring B-field in the vicinity of SMBHs

- AGNs are known to have hot coronae ($T \sim 10^9$ K).
- Heated by magnetic reconnections (Liu, Mineshige, & Shibata '02).
- If a corona is magnetized, synchrotron (cyclotron) radiation is expected (Wardzinski & Zdziarski '00, '01; YI & Doi '14).
- Synchrotron radiation will tell us about the magnetic field strength and its structure (polarization).

http://alma.mtk.nao.ac.jp
Expected Coronal Synchrotron Emission for the case of IC 4329A

- Coronal properties are constrained by Suzaku/NuSTAR joint observation (Brenneman+’14).

- \( T_e = 50 \text{ keV}, \tau_e = 2.34 \)

- Non-thermal population for the MeV background (YI, Totani, & Ueda ’08).

- Synchrotron-self absorption is effective below sub-mm.
ALMA Observation toward NGC 985

- ALMA Cycle-3 Observation on 2016/03.

- The excess is confirmed.
  - with the size of <0.02 arcsec (<16pc).
  - first discovery of the millimeter excess in Seyferts.

- Coronal Synchrotron emission is the most likely.
  - But, currently not clear whether it is thermal or hybrid.

- Our ALMA Cycle-4 proposal is recently accepted for higher frequency observations and another object.
Summary

- Utilizing SDSS-NVSS quasar samples (~8461 quasars), we study the disk-jet connection.

- Jet power correlates with disk luminosity.
  - But, the jet production efficiency is ~0.7%.
  - Blazars’ prediction may be overestimated by the assumption on $\gamma_{\text{min}}$.
  - Slowly spinning BHs (a~0.1) assuming magnetic field strength from simulation.

- Coronal synchrotron emission will tell us the B-field strength.
  - We have already detected the coronal synchrotron emission with ALMA.